Technical Note

TN 6.22 StormTech® Subgrade Performance Considerations

Overview

StormTech chambers, as buried arch structures, concentrate overburden loads at the chamber feet and spaces between rows of chambers. A foundation layer of crushed stone under the feet of the chambers is used to partially disperse these concentrated loads to an appropriate bearing pressure on the subgrade. It is the responsibility of the consulting engineer to determine the foundation stone depth for the specific chamber application based on the overburden loads and allowable subgrade bearing capacity.

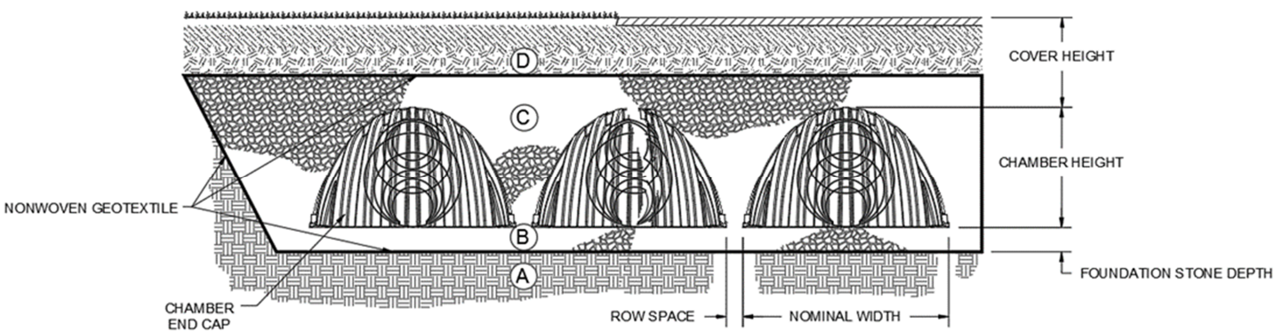
StormTech provides Minimum Foundation Depth tables in the chamber Design Manuals (Ref. 4 & 5) from which a system designer may compute the required depth of foundation stone based on cover height above the system and allowable bearing pressure of the subgrade as determined by the consulting engineer. The Minimum Foundation Depth tables are based on a simplified assessment of foundation pressures (described below), which may not be appropriate for all site conditions. Additionally, these design tables are for common spacings between chamber rows. Specific chamber applications may utilize row spacings not covered by the tables. Thus, the design tables do not constitute foundation designs for all design conditions. This Technical Note discusses foundation performance limits for StormTech and explains how bearing pressures and loaded area below a StormTech bed may be calculated per ASTM F2787. It is intended to support consulting engineers in determining site-specific allowable bearing pressures and as a resource for system designers in selecting proper foundation stone depths for all configurations of cover height and chamber row spacing.

Loading Scenario

Figure 1 depicts a typical StormTech cross-section. Pressure is applied to the subgrade from the dead load of the embedment stone, the overlying fill, and the surface pavement section as well as any effects of surficial live loads. The arch shape of StormTech Chambers concentrates the overburden loads about the chamber feet and row spaces between. See ASTM F2787 (Ref. 1) for specific guidance on evaluating these loads.

Figure 1

Typical Cross-Section of StormTech System



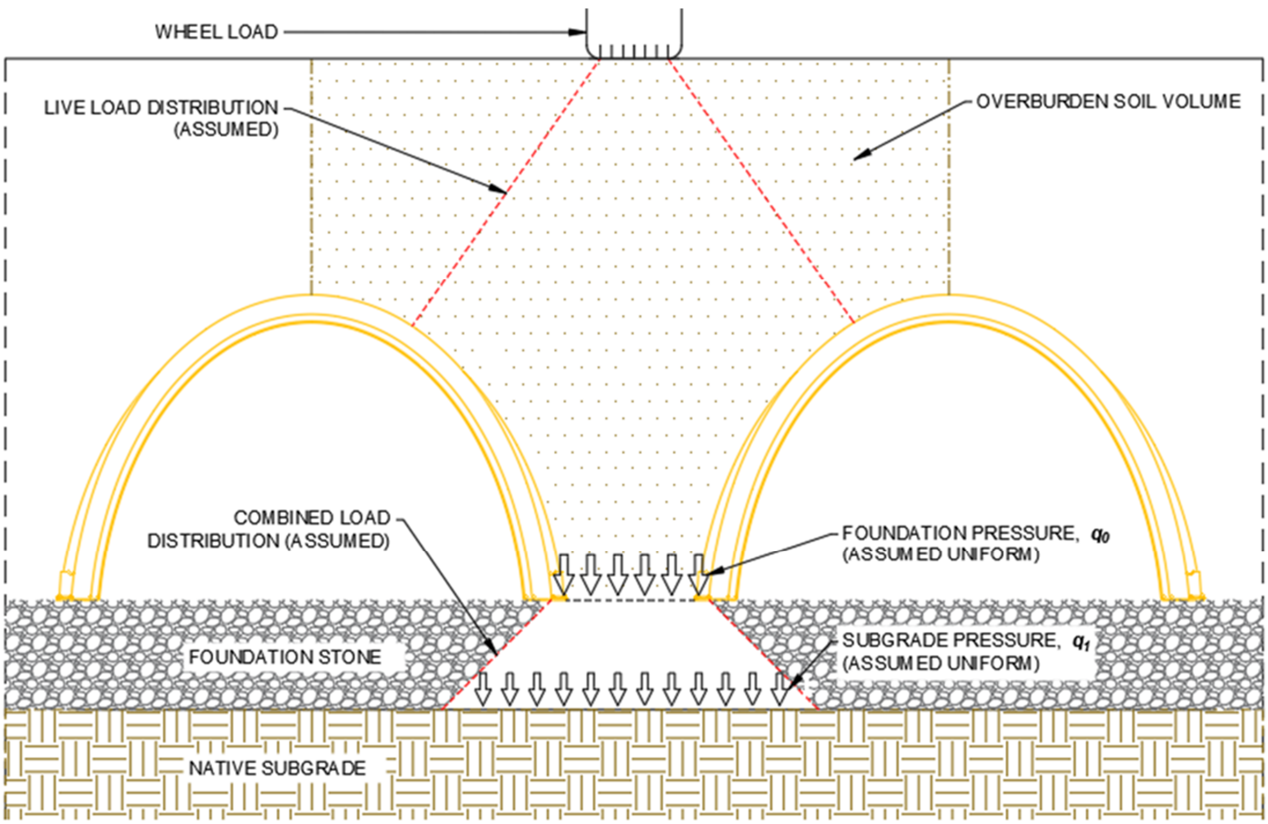
MATERIAL DESCRIPTIONS

A – Native Subgrade B – Foundation Stone C – Embedment Stone D – Site Fill

The actual load effects on the StormTech foundation layer and on the subgrade are complex. To create the Minimum Foundation Depth tables in the chamber design manuals (Ref. 4 & 5), StormTech simplified the assessment by assuming live loads and combined loads (dead + live) act as uniform pressure distributions, which decrease linearly with depth. **Figure 2** depicts the conceptual loading model used by StormTech. The surficial live loads (typically assessed as the AASHTO Design Truck per Ref. 2) and the dead load of the overburden combine at the base of the chamber. The combined load is assumed to act as a uniform strip pressure, q_0, over a width equal to the row space plus twice the effective foot width of the chamber. The combined load then distributes through the foundation stone layer to reach a uniform subgrade pressure, q_1 (where $q_0 > q_1$). Note that the linear load distributions assumed in this assessment and shown in **Figure 2**, may underestimate the pressure on the foundation layer or subgrade at certain points and thus may not be appropriate for detailed geotechnical assessment. However, these assumptions are consistent with AASHTO (Ref. 2 & 3) and are considered reasonable if used in conjunction with a factor of safety on the subgrade capacity of 2.5 or greater (Ref. 1).

Figure 2

Conceptual Loading Diagram of the StormTech Subgrade (N.T.S.)



The dimensions of the row spacing, cover height above the chambers, and foundation stone depth below the chambers are critical to the magnitude of the applied subgrade pressure q_1. Although row spacing can be increased, standard (minimum) row spacing is 6 inches (152 mm) for the MC-3500, DC-780 and SC-series chambers and 9 inches (229 mm) for the MC-4500. The SC-160 chamber is unique since SC-160 chambers are designed to abut each other with no additional row spacing. Cover height is usually determined by the site design and hydraulic considerations. That leaves foundation stone depth as the primary design parameter for controlling pressure on the subgrade. The Minimum Foundation Depth tables (Ref. 4 & 5) establish stone depth as a function of cover height to limit the applied pressure q_1 to a site's allowable bearing pressure. Refer to **Table 1** for product-specific dimensions and foundation design table references.

Subgrade Performance Considerations

Determination of allowable bearing pressure is routine geotechnical practice which involves consideration of ultimate bearing capacity (resistance to shear failure), settlement conditions, local expertise, and other site- or project-specific factors. The discussion below is meant to assist geotechnical designers in evaluating some of the unique characteristics of StormTech. However, it is not a complete list of considerations and in general the native subgrade below a StormTech system must be stable and unyielding for proper function of the system and for protection of surface developments.

BEARING CAPACITY	Bearing capacity failure is not tolerable. Local shear (punch shear) is an important design consideration, given the narrow row spacing and relatively thin over-loaded zone of the subgrade.
SETTLEMENT	The chamber system is tolerant to minor settlement. However, for design, total settlement at any point should be limited to 3 inches (76 mm). Differential settlement should not exceed 1 inch (25 mm) across one chamber structural span (span varies by product. See **Table 1**). Settlement tolerances are intended to provide the basis for foundation design and ensure structural performance of the chamber-soil system.
SUBGRADE SATURATION	If the system design allows for infiltration (i.e. no impermeable liner is specified) then water content of the subgrade soil is expected to increase above natural levels immediately after a storm event. The degree of saturation will depend on the hydraulic conductivity of the subgrade and the storm intensity among other factors. If an impermeable liner is to be used, then it can be assumed the StormTech system will not increase the saturation of the subgrade.

Minimum Foundation Depth Tables & LRFD

The following section provides commentary to support use of the StormTech Minimum Foundation Depth tables (Ref. 4 & 5) when subgrade capacity recommendations are provided under a load and resistance factor design (LRFD) framework. The Minimum Foundation tables are formatted to be directly used for sizing the foundation through an allowable stress design (ASD). If the project's geotechnical recommendations are written for an LRFD approach, then additional interpretation of the recommendations may be required to ensure a minimum total factor of safety is maintained.

General Overview of Shallow Foundation Design by ASD & LRFD

Design of shallow foundations is generally concerned with limiting settlements to tolerable levels (service limit state, SLS) and preventing bearing capacity failure (ultimate limit state, ULS). In the ASD approach—which is the prevailing practice in the United States—the actual, or unfactored, loads on the foundation [Q_f] are designed to be less than an allowable bearing pressure [R_{abp}] (Eqn. 1). The allowable bearing pressure in this framework is a combined limit representing the minimum of the unfactored SLS and the factored ULS (Eqn. 2). Typically, geotechnical reports provide just an allowable bearing pressure recommendation for each shallow foundation type and bearing stratum. Supporting values for the ULS, SLS, and the factors of safety [SF] are often not given.

$$Q_f \leq R_{abp}$$ **[Equation 1]**

$$R_{abp} = \min\left(SLS, \quad \frac{ULS}{SF}\right)$$ **[Equation 2]**

In the LRFD approach, partial factors are applied to the foundation load (load factors, [γ]) and to each limit state of the subgrade (resistance factors, [φ]). Each limit state is then designed for separately. For the SLS, load and resistance factors are set to one (or unfactored) as shown in Equation 3. When geotechnical recommendations are formatted for LRFD, ULS and SLS design capacities are listed separately. Typically, the ULS is given with a resistance factor applied, however the factor value may not be stated explicitly.

$$Q_f \leq SLS$$ **[Equation 3]**

$$\gamma Q_f \leq \varphi ULS$$ **[Equation 4]**

To compare the factor of safety at the ULS in ASD and the combined factors in LRFD, the basic design equations can be rearranged as shown below in Equations 5 and 6 (Note: for simplicity, a single load and load factor is considered in the LRFD equation). In this case, an equivalent total safety factor for the LRFD design can be found by dividing the load factor by the resistance factor.

$$Q_f \leq \frac{ULS}{SF} = \frac{\varphi ULS}{\gamma}$$ **[Equation 5]**

$$SF = \frac{\gamma}{\varphi}$$ **[Equation 6]**

Application of LRFD Recommendations to StormTech Design

The column heading values in the StormTech Minimum Foundation Depth tables are the unfactored bearing pressure on the subgrade for the corresponding chamber, cover depth, and foundation thickness—equal to [Q_f] in the above equations. If sizing the foundation based on ASD subgrade recommendations, the allowable bearing pressure may be directly compared the column headings, per Equation 1. If sizing the foundation based on LRFD recommendations, the following should be considered.

The SLS capacity may be compared directly to the bearing pressure, per Equation 3. Note that the SLS will be based on design settlement tolerances, which may be different than the recommended settlement limits StormTech provides in this Tech Note (Section: Subgrade Performance Considerations). It is the site designer's responsibility to set settlement limits for the site—StormTech recommendations are provided for guidance only.

The ULS capacity may be compared to the bearing pressure, per Equation 4. Since no load factor is applied in the StormTech tables, the recommended ULS may need to be scaled per Equations 5 and 6, to maintain an appropriate total safety factor. StormTech recommends a total safety factor of 2.5 or greater for foundation design (Ref. 1), however, the design factors for each project are the responsibility of the designing engineer. If the resistance factor on the ULS was not provided by the geotechnical engineer and cannot be requested, StormTech recommends assuming a value of 0.6. Example conversions of the factored ULS are shown below.

Example #1: *Geotechnical report specifies a factored ULS of 5 ksf (240 kPa). Resistance factor for the ULS is listed as φ=0.4. Calculate an adjusted ULS representing a total safety factor of 2.5.*

$$SF_{eq} = \frac{\gamma}{\varphi}$$ *per Eqn. 6*

$$SF_{eq} = \frac{(1)}{(0.4)} = 2.5$$ *Equivalent safety factor meets the recommendation*

$$\boldsymbol{Q_f \leq 5\,ksf\ (240\,kPa)}$$ *Answer. The factored ULS may be used directly with the StormTech foundation tables, since the total safety is at least 2.5*

Example #2: *Geotechnical report specifies a factored ULS of 5 ksf (240 kPa). No resistance factor listed, assume φ=0.6. Calculate an adjusted ULS representing a total safety factor of 2.5.*

$$SF_{eq} = \frac{\gamma}{\varphi}$$ *per Eqn. 6*

$$SF_{eq} = \frac{(1)}{(0.6)} = 1.7 < 2.5$$ *Equivalent safety factor is less than recommended*

$$Q_f \leq \frac{ULS}{SF} = \frac{ULS}{SF_{eq}}\left(\frac{SF_{eq}}{SF}\right)$$ *per Eqn. 5*

$$Q_f \leq (5\,ksf)\left(\frac{1.7}{2.5}\right)$$

$$\boldsymbol{Q_f \leq 3.4\,ksf\ (160\,kPa)}$$ *Answer. Adjusted ULS*

Table 1
StormTech Chamber-Specific Dimensions and References

Chamber	Standard Row Spacing	Effective Foot Width[a]	Soil Column Width[b]	Structural Span[c]	Minimum Foundation Depth Table
MC-4500	9” (230 mm)	4.5” (115 mm)	18” (460 mm)	91” (2433 mm)	MC-Series Design Manual Table 2
MC-3500	6” (150 mm)	3.5” (89 mm)	13” (330 mm)	70” (1737 mm)	MC-Series Design Manual Table 1
DC-780	6” (150 mm)	2.5” (64 mm)	11” (279 mm)	46” (1156 mm)	SC-Series Design Manual Table 2
SC-740	6” (150 mm)	2.5” (64 mm)	11” (279 mm)	46” (1156 mm)	SC-Series Design Manual Table 1
SC-310	6” (150 mm)	2.5” (64 mm)	11” (279 mm)	29” (716 mm)	SC-Series Design Manual Table 1
SC-160	0” (0 mm)	3.5” (89 mm)	7” (178 mm)	18” (460 mm)	SC-Series Design Manual Table A-1 (Addendum)

<u>*Table Notes*</u>
[a] *The effective chamber foot width is the distance from the outside of the foot to the centroid of the corrugation.*
[b] *Soil column width = (Row Space) + 2*(Effective Chamber Foot Width).*
[c] *Chamber structural span is the distance between centroids of opposing corrugations at the chamber foot level. The differential settlement tolerance for each product type is based on the structural span.*

References

1. *ASTM F2787* – “Structural Design of Thermoplastic Corrugated Wall Stormwater Collection Chambers”
2. *AASHTO Bridge Design Specifications, Section 3* – “Loads and Load Factors”
3. *AASHTO Bridge Design Specifications, Section 12* – “Buried Structures and Tunnel Liners”
4. *StormTech MC-3500 & MC-4500 Design Manual, Section 2.0* – “Foundations for Chambers”
5. *StormTech SC-160LP, SC-310, SC-740, & DC-780 Design Manual, Section 4.0* – “Foundations for Chambers”